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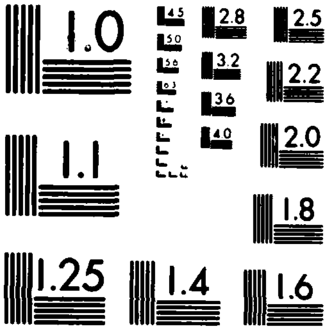

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Investigation of Three-Dimensional Mesh Generation With Precise Controls

Interm Scientific Report

Principal Investigator: Peter R. Eiseman

(October 31, 1983 - September 30, 1984)

Columbia University
New York, NY 10027

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During this period, the development of algebraic and adaptive grid techniques were continued and brought into a more refined state. Included were the topics of multisurface transformations together with Boolean operations, pointwise distributions on curves, two-dimensional surface grids embedded in three-dimensions, three-dimensional volume grids and the adaptive strategies of mean value relaxation, alternating direction, and center of mass relaxation for triangular meshes. Of paramount importance in the various adaptive strategies was the utilization of weighting functions, which was studied and still requires further development.

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BACKGROUND

During the period of Grant No. AFOSR-82-0176[illegible] ending in September 1984, the development of algebraic and adaptive grid techniques were continued and brought into a more refined state. Included were the topics of multisurface transformations together with Boolean operations, pointwise distributions on curves, two-dimensional surface grids embedded in three-dimensions, three-dimensional volume grids and the adaptive strategies of mean value relaxation, alternating direction, and center of mass relaxation for triangular meshes. Of paramount importance in the various adaptive strategies was the utilization of weighting functions which was studied and still requires further development.

In addition to the specific developmental tasks, a major review article was prepared for the Annual Review of Fluid Mechanics [1]. This prestigious publication operates on an invited-only basis and produces one book each January in which various topics of importance are surveyed for the typical practitioner in fluid mechanics. More important than the prestige is the rather wide readership, and therefore, the opportunity to solidly establish the role of grid generation in fluid mechanics simulation and to present the fundamental structure and concerns of the topic. The guidelines appropriately given by the publisher were to develop the significant aspects of grid generation rather than to attempt a comprehensive account of everything that was done. It is interesting to note that previous reviews had taken the comprehensive route and had resulted in somewhat lengthy and unwieldy manuscripts. The current review, by contrast, was shorter and I believe is easier for an uninitiated person to follow and to quickly gain a suitable perspective of grid generation.

After a short introduction, a general setting is established so that the reader can see what the basic issues are without the constructive technicalities of the various methods. The two major classes of methods correspond to constructions in terms of explicit algebraic formulas and in terms of implicit definitions given by solutions to differential equations of various sorts. The class of algebraic methods was presented first with the development leading up to the multisurface transformation and its combination with Boolean operations. Next, the differential equations approaches were examined with an emphasis on those of the elliptic type. In each development, the central role was played by the element of control which is necessary to address the various constraints that arose from the general setting established for arbitrary applications. The aspect of control was further amplified in the adaptive context in which all of the prior development comes together. As a unifying theme, the general concept of a monitor surface was presented and was seen to be the common part of all adaptive methods regardless of their internal contructive technicalities.

A further project which was related to the specific developmental tasks was the selection of suitable computer equipment to use for those tasks in the future. The funds are being supplied by a DoD equipment funding grant under a program for DoD research at universities. Due to the long lead time between the proposal stage and the funding stage combined with a rapidly changing technology, an evaluation had to be conducted to obtain the best possible equipment for the allotted funds. For the generation of three-dimensional and adaptive grids, the IRIS 1500 by Silicon Graphics was selected over the originally proposed Appolo System. The IRIS is called the "geometry computer": it does geometric manipulations at a very rapid rate because of specially dedicated VLSI chips. Moreover, it is also a computer which is as fast as a VAX 11/750, has 8.5 Mb of CPU memory, 24 bit planes, and a file serving capability. Because of the built-in geometric powers, the basic computational power remains virtually unburdened. This combination is ideal for the grid problems where computing can be dynamically and locally combined with geometric manipulations. For example, the interplay between an adaptive grid movement strategy and a solution algorithm can be examined in real time.

For the adaptive triangular mesh strategy, a paper was written, was presented at a conference, and was submitted to the associated societal journal [1]. This was co-authored with my earlier graduate student Gordon Erlebacher who is now a scientist at NASA Langley Research Center in the Computational Methods Branch.

For the mean value relaxation technique, the conference version [3] was revised for the ASME Journal of Fluids Engineering to include a more detailed explanation of terminology (to satisfy reviewers) and, more importantly, to include the establishment of motion barriers. The need for such barriers was not seen by reviewers. This need stems from the use of local bilinear mappings to uniquely define a continuous monitor surface at any instant from grid-like data. Under the action of the movement molecule, the central point is moved to a parametric location contained within the Cartesian parameter space molecule. When the surface quadrant points not in the molecule are not out of scale with other such points, the new point on the surface is within the geometric surface molecule. However, the new point must be connected to its nearest coordinate points. If unchecked, such a connection could possibly intersect such an existing condition. The check established was to create motion barriers by extending segments at concave corners of the molecule to place constraints upon the choices of maximum movement distances along coordinate curves. In the paper these were denoted by d_A, d_B, d_C and d_D. When one quadrant point severely stretches its quadrant, further limitation is required on the maximum movement distances. When the transformation is evolving in a reasonably smooth way, however, this latter limitation is not required. This is almost invariably the case. The only exceptions would come from situations such as highly distorted and stretched initial conditions which would also be unsuitable for a solution algorithm on virtually any simulation of a physical problem. In summary, the motion barriers permit us to adapt grids with any strength of weight without any worry about a possible grid overlap.

For the variational strategy, work has proceeded jointly with P.J. Roache and S. Steinberg. Steinberg has focused primarily on symbolic manipulation; Roach, on the interaction with solvers; and myself, on surface integral formulations. All of us have interactively worked together on various planar integral formulations. Proposed formulations are tested rapidly due to the use of symbolic manipulation to generate the necessary FORTRAN code which produces a local difference molecule. With the molecule, standard numerical techniques are employed to generate the grid.

In the alternating direction strategy [4] and in the adaptive multisurface applications under current development, the use of weight functions along curves is crucial. Considering distributions only on curves, a method of local manipulation was developed and a method for the generation of arbitrary distributions was extended. The local manipulation allows one to specify a region in which points are clustered into a strictly smaller subregion. This is accomplished with a continuous weight which pushes region points into the desired subregion. Outside the main region, the distribution of points remains unchanged. The resulting transformation is globally derivative continuous. When used within the interactive environment, pointwise distributions along curves can be locally manipulated and fine tuned for an application while elsewhere a satisfactory distribution is not destroyed or moved away from its appropriate location. When used in the adaptive context, it is expected that we will obtain the capability to locally adapt the grid while maintaining derivative continuity everywhere.

In the method for arbitrary distributions along curves, an extension was made to bring the geometric construction of distributions to curves in surfaces rather than just in planes. This geometric construction provides a natural interpretation of implicitly contained intrinsic quantities and represents an alternative to the linear weights used in [4]. A paper detailing the construction and the extension is in preparation.

With the multisurface transformation, a tensor product construction [1] has been examined and will be explored further. The idea is to specify a coarse sparse control grid which approximates but does not precisely match a region. The tensor product defines a smooth analytical transformation which also approximates the region. The internal points are free to move about and are thus free to manipulate the grid. This manipulation is local if the multisurface interpolants are also local. The payoff here is that with a modest amount of specified data, we can approximate a desired grid structure and the boundaries of our region. This is particularly attractive in three dimensions where specified data could reach enormous proportions. To obtain an exact match to given boundaries, a local blending would then be required.

In the same spirit as the tensor product structure for coordinate generation, surfaces can also be mathematically represented. This represents an alternative to existing techniques for free-form surface design. In summary, what is being considered here is free-form coordinate generation as well as that of surface design.

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